Dewatering and Drying Characteristics of Water Hyacinth (*Eichhornia Crassipes*) Petiole. Part II. Drying Characteristics

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ABSTRACT

The broad objective of the study was to identify and relate the parameters that are important in drying of water hyacinth petiole. This involved identification of the pertinent properties that influence drying of water hyacinth petiole and then developing predictive empirical equations for the identified factors. Field work involved collection of samples from four different locations within Nairobi dam. A series of experiments were carried out using a standard oven to obtain the drying data and the subsequent drying curves. Mean drying rate (k_{mean}) derived from the experimental data was used to develop predictive equation that adequately described the effect of varying both drying temperature and current moisture content of samples during the drying process. Mean drying rates, k_{mean} were found to be 2.22, 2.71 and 3.39 h^{-1} for oven drying temperatures of 105, 130 and 150^{o}C respectively. It was evident that increasing the drying temperature resulted into an increase in drying rate whereas a change in the moisture content of the sample before drying, did not affect the drying rate at a constant drying temperature with a P-value of 0.97 at a significance level of 0.05. Mean initial moisture content of water hyacinth petiole was found to be 91% (w.b.) for 16 determinations. Statistical investigation showed that there was no significant difference in the means of the initial moisture content (P-value = 0.94) for the samples collected at the four locations within Nairobi dam. A two paired t-test between predicted drying rates and mean drying rates obtained from experiments gave a P-value of 0.99. The significance of this study is seen in the role the results obtained will have in influencing the design of suitable drying equipment.

Keywords: Drying, hyacinth, moisture, petiole, temperature, Kenya

1. INTRODUCTION

Water hyacinth is botanically known as *Eichhornia crassipes* (Ogunye, 1988). According to Ogwang (2007), water hyacinth is native to South America. Barrett (1989) and Sophie (2006) have reported that the plant is thought to have originated in the Amazon basin and the extensive lakes and marshes of the Pantanal region of western Brazil. It was then widely introduced throughout North America, Asia, Australia and Africa. Schmitz *et al.* (1993) also reported that water hyacinth was introduced into the U.S. in 1884. It is noted that water hyacinth reached Africa as early as late 18th century. Between 1880 and 1980, water hyacinth appeared as an ecological nuisance in many parts of Africa. It caused a population crisis in

South Africa in the 1910s, Madagascar in the 1920s, Tanzania, Uganda and Kenya in the 1930s through to the 1970s. In the 1980s and 1990s, water hyacinth bloomed heavily on Lake Victoria, the Nile, the Congo and almost all watercourses in Africa (Kitunda, 2006). Its minimum growth temperature is 12^{o} C (54^{o} F); its optimum growth temperature is 25-30^{o} C (77-86^{o} F); while its maximum growth temperature is 33-35^{o} C (92-95^{o} F) (Kasselmann, 1995). Water hyacinth is found globally in the tropics and subtropics and is considered as one of the worst weeds in the world-aquatic or terrestrial (Holm *et al.***,** 1977). Plate 1 illustrates how water hyacinth can chock a water body and be an environmental nuisance and threat to eco-diversity.

Figure 1. Water Hyacinth, Eichhornia crassipes. (University of Florida, 2001). Photos stitched by ArcSoft software.

Manually cleared water hyacinth initially contain about 95.8% water, which can be reduced to only 72% after 15 days with temperatures and humidity averages of 25^{o}C and 68%, respectively (Solly, 1984). Book (1969) found out that water content of water hyacinth, derived from the mean of 82 determinations, was 93.4%. This high moisture content hinders the transportation and processing of water hyacinth as a resource (NAS, 1977). Manual control programmes have been implemented in several lakes, rivers and dams to remove the weed from the water bodies, leading to the accumulation of large mounds of water hyacinth along the water bodies. These mounds have very high moisture content and their drying and decompositions rate are too slow causing them to rot and produce noxious odour along the water bodies. The smell from the rotten heap of mechanically removed hyacinth has a potential negative environmental impact to the surrounding. Moreover, the mounds have a negative visual impact especially for tourists. Concern over the high moisture content can be addressed so as to alleviate serious constraint to its transportation and processing for utilization.

According to Mailu *et al*. (2000), harvesting of water hyacinth must be linked to a programme of utilization for it to be justifiable. Local communities within the affected water bodies have already done this on a limited scale. A good example is Hyacinth Crafts within Winam Gulf, with assistance from the Kisumu Innovation Centre Kenya (KICK). Since 1998, KICK has developed several household items using water hyacinth fibre, as reported by Olal *et al*. (2001). Moreover, many other products can be processed from dry water hyacinth plant (Thyagarajan, 1984). Its fibre can be used as a resource to make handicrafts that provide an important source of income for the affected communities (Lindsey and Hirt, 2000). It has been reported by Olal (2005) that one way to increase the utilization of water hyacinth is to turn its apparent disadvantage into opportunity and that everyone wins when we turn this terrible weed into organic fertilizer, livestock feed or furniture. This can be done by innovating ways of drying it hence increasing the production of fibre products by crafts people and cottage industries. Utilization of water hyacinth is an important way of managing the weed problem and contributing to environmental management as well as creating employment and generating income for those who are most affected by it.

Water hyacinth is better suited to the production of coarse fibre products. The process was first patented in the United States in 1926 (Callahan, 1926). Research teams at Universities in Florida and California have reported failure in overcoming processing constraints. One widely experienced processing problem is the high moisture retention of fibers, rendering it unacceptable for high-speed pressing. The pulp from the petiole (stalk stem) appears better suited to the fabrication of particle board (Gopal, 1987). One alternative approach has been its incorporation into cement (reinforced) pressed boards or into waxed paper (Ghosh *et al.*, 1984).

The broad objective of the study was to identify and relate the pertinent parameters required in drying of water hyacinth petiole. The specific objectives were to:

1. Identify properties that influence drying of water hyacinth petiole.
2. Develop predictive empirical equations of the properties identified in (1) above.

Pertinent drying parameters were obtained from numerous research works on plant materials as cited in this study. These parameters were tabulated as shown in Table 1.

Table 1. Parameters affecting drying characteristics

Parameters	**Description**	**Source**
mc	Moisture content (%wb)	Kang *et al*. (1984); Koegel and Bruhn (1972); Li *et al*. (1989); Savoie and Beauregard (1990); Zhang *et al.* (1989)
t	Time (hours)	Rotz and Sprott (1984)
T	Drying temperature (^oC)	Mburu *et al.* (1995b)

2. MATERIALS AND METHODS

Field work for this study involved collection of samples from four different locations within Nairobi dam. Water hyacinth petioles were separated from the leaves and the roots in the laboratory. Samples were oven dried to determine the effect of increasing temperature on drying samples. Exponential series models that described the relationship between moisture content and drying time were obtained. The site selection & description, field sampling and laboratory sample preparations are as described in Part I of this study.

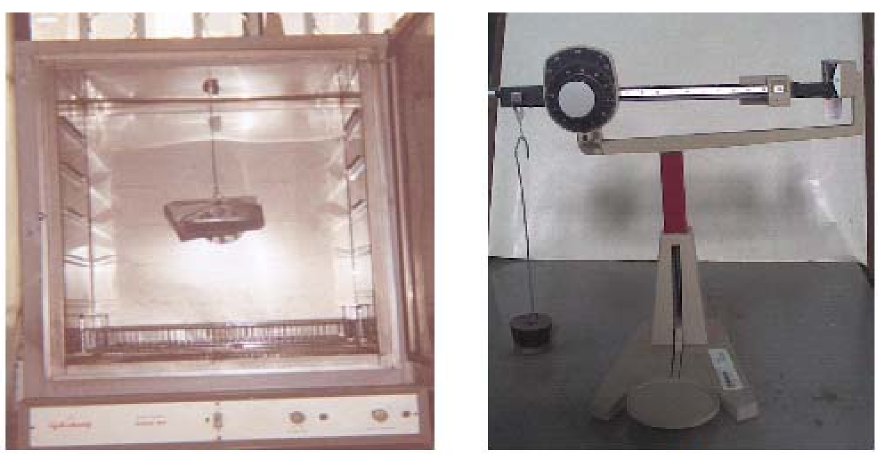
2.1 Experimental Layout

The identified parameters were investigated by conducting oven drying of water hyacinth petiole samples. The samples were weighed, packed in labelled plastic bags and stored in a refrigerator (Friendman 13, DE LUXE) set at the lowest design temperature of 12^{o}C to keep them fresh and prevent moisture loss or gain.

2.1.1 Drying

The oven which was used to dry the samples is the standard GALLENKAN BS OVH-220-210Y oven size number 3, 220-240 V and 50Hz. The oven can operate at a temperature range of 0^{o}C to 240^{o}C. The samples were subjected to drying temperatures of 105, 130 and 150^{o}C so as to investigate the effect of increasing temperature on drying samples during oven drying. Varying drying temperatures have been reported in literature, for instance, Beshada *et al.* (2006) used 105°C to dry kernels of barley, maize, sorghum and wheat; Jekayinfa (2006) used 130^{o}C on locust bean seed while West *et al*. (2001) used up to 150^{o}C on rice. Wong *et al*. (1999) reported that temperatures beyond 200^{o}C could thermally degrade fibre.

A straight wire of 1 m in length was used to connect an analogue mass balance (design sensitivity of 0.01 g) at the top of the oven and the container holding the sample in the oven. The container holding the sample was suspended in the oven. The length of the wire was long enough to protect the balance from oven heat and also allowed the loss of weight of water hyacinth petiole to be recorded regularly without interfering with the constant drying temperature inside the oven. The vent seal was placed in position to avoid escape of heat during the experiment. This arrangement is shown in Figure 2 (a) and (b).



(a) (b)

Figure 2. (a) Shows sample in a drying position in the oven while (b) shows mass balance secured on top of the oven.

2.2 Development of Predictive Equations

The drying pertinent parameters can be related by:

$$MR = f(mc, t, T.......) \qquad [1]$$

Where;
mc = moisture content
t = drying time
T = drying temperature and,

It was desirable to satisfy all of these parameters in one predictive equation. Therefore the relationship between drying time and temperature was tested to investigate the effectiveness of changing the drying temperature, whereas a model developed by Rotz and Sprott (1984) was used to relate moisture ratio to drying time:

$$MR = \frac{M_t}{M_o} = \exp[-k(t - t_o)] \qquad [2]$$

Where:

MR = Moisture ratio
M_t = Moisture content on dry basis at time (t)
M_o = Initial moisture content on dry basis at time t_o
k = drying rate (h^{-1})
$(t - t_o)$ = duration of drying (h)

The exponential equation was used when equilibrium moisture content was set to zero. The importance of the equilibrium moisture content is seen in its capability to describe the final attainable moisture content of the product after complete drying or dehydration as zero (Koegel and Bruhn, 1972). Plots of moisture content at any time (M_t) against drying time (t) gave exponential series model of the form; $A = C\exp(-Dt)$ for oven drying experiments of water hyacinth petiole.

3. RESULTS AND DISCUSSION

3.1 Drying

Drying has been defined as a process that frees wet material of its liquid or moisture content by exposing the material to a particular drying temperature, whereas dehydration is defined as loss of all liquid or moisture content from a material. Dehydration can thus result from a drying process. In the perspective of this study, the drying process of water hyacinth petiole samples was continued until the samples reached zero equilibrium moisture content (otherwise referred to as dehydration). However for the purposes of consistency in reporting, the whole process including the point of zero equilibrium moisture content was reported as drying. The drying process yielded a relationship between moisture content and drying time that enabled the prediction of drying rates for the range of drying temperatures used.

3.1.1 Effect of Sampling Locations; S1, S2, S3 and S4

One-way ANOVA to determine whether there was a significant difference of the mean initial moisture content of the samples at the four sampling locations showed strong indication that the location of sampling within the dam did not affect the initial moisture contents for 16 determinations at a significance level of 0.05 with a P-value of 0.94.

3.1.2 Moisture Content-Drying Time

Plots of current moisture content against drying time are shown in Figures 3, for samples whose moisture content were reduced to 40% (w.b) before oven drying. It was appreciated that the curves portrayed typical falling exponential trends such that when drying time was zero then the moisture content on the graph was equivalent to the current moisture content of the sample before drying commenced. The falling trend of the graph of samples dried at 105^{o}C was less rapid compared to the ones dried at 130 and 150^{o}C. Similar findings have been reported by Mburu *et al.* (1995b) while working on coffee pulp.

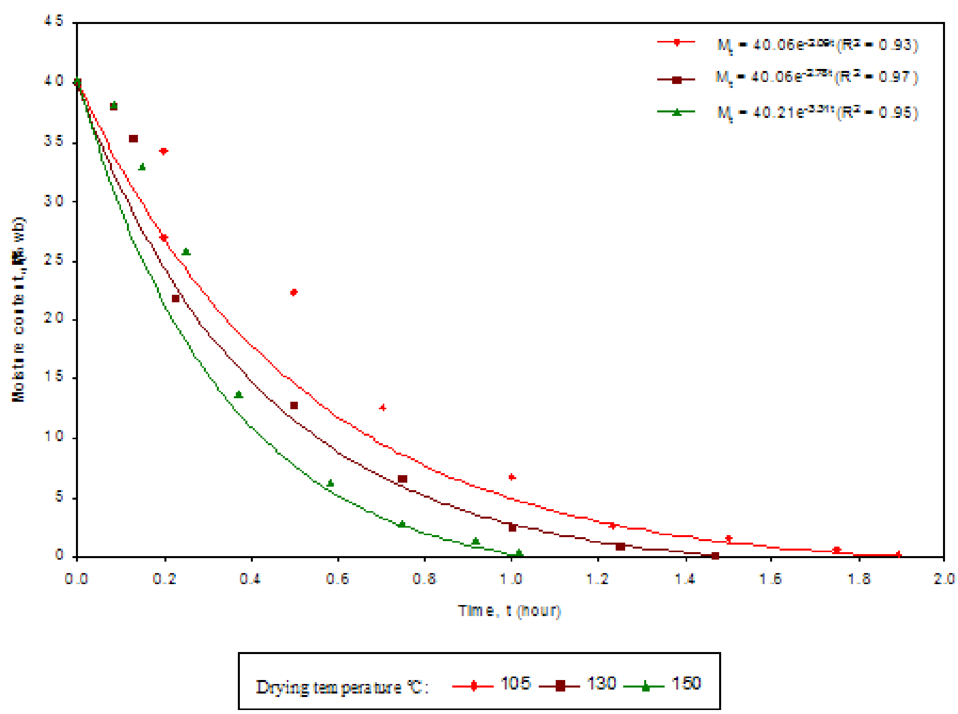


Figure 3. Current moisture content against drying time

3.1.3 Increase of drying temperature on drying rate

The effect of increasing the drying temperature on drying rates was investigated for all the samples at moisture contents of 40, 45, 50 and 55% respectively. Table 2 shows drying rates obtained from these samples and that obtained from fresh sample with initial moisture content of 91% (w.b). It was observed that increase in drying temperature resulted into an increase in drying rate. However, difference in moisture contents of samples did not affect the drying rate at a constant drying temperature as supported by ANOVA analysis that gave a P-value of 0.97 at a significance level of 0.05. Samples that had lower moisture content before drying dried faster, for instance at 0.75 hours, the samples that had a moisture content of 40% had been reduced to 6.52% while sample with moisture content of 91% had been reduced to 26.03% when dried at a temperature of 130^{o}C with a mean drying rate of 2.71 per hour. In similar but separate studies, Henderson and Henderson (1968), Thompson *et al*. (1968) and Barre *et al*. (1971) reported that drying rate values are dependent upon drying temperature during drying of corn.

Table 2. Comparison of drying rates, k (h^{-1}) at different drying temperatures and varying moisture contents.

Drying temperature (^{o}C)	**Moisture contents of samples (% wb)**				
	40	**45**	**50**	**55**	**91 (no moisture reduction)**
105	2.09	2.03	2.63	2.37	1.97
130	2.78	2.82	2.82	2.58	2.54
150	3.31	3.30	3.53	3.19	3.63

Figure 4 shows the linear relationship between predicted drying rates and drying temperatures of water hyacinth petiole samples. The y-intercept at which $k_{predicted}$ equals to zero gave the temperature at which drying would take longest. The temperature was found to be 23.66^{o}C and interestingly was within the range of room temperature (19 to 27^{o}C) during experimentation.

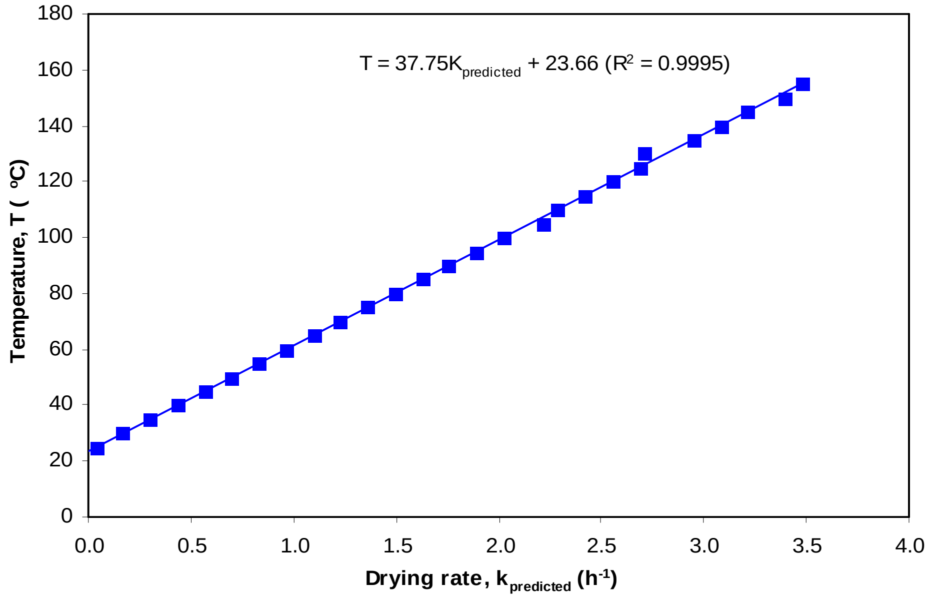


Figure 4. Drying temperature against predicted drying rate

Table 3 gives the values of predicted drying rates, $k_{predicted}$ (h^{-1}) alongside the mean drying rates, k_{mean} (h^{-1}) obtained from experiment for samples dried at 105, 130 and 150°C.

Table 3. Predicted drying rates and mean drying rates obtained from experiments

Drying temperature (°C)	**Drying rate, k (h^{-1})**	
	k_{mean}	$k_{predicted}$
105	2.22	2.16
130	2.71	2.82
150	3.39	3.35

A two paired t-test between predicted drying rates and mean drying rates obtained from experiments gave a P-value of 0.99. It was noted that the drying rate of fresh sample with no moisture reduction were lower compared to those whose initial moisture content had been reduced. Keener (1991) reported similar findings while investigating several values of drying rates for grains. This could be attributed to the waxy surface on the cuticle that had been mechanically exposed during moisture content reduction by triaxial compression, the triaxial compression procedures are described in section 2.5 of Part 1 of this study. The waxy surface was not interfered with in the absence of triaxial compression. Exposing the waxy surface on the cuticle also resulted into increased moisture migration to the sample surface due to increased drying rate at increased drying temperature.

These findings described drying characteristics of water hyacinth petiole accurately for the identified pertinent parameters.

4. CONCLUSIONS

The sampling site within Nairobi dam did not affect the initial moisture content of water hyacinth petiole samples. It was appreciated that the results of the relationship between current moisture content, (M_t) and drying time, (t) gave a typical falling exponential trend. Increase in drying rate was as a result of the effect of increasing the drying temperature. The fact that water hyacinth petiole samples dried faster at higher temperatures was ascertained. As a result, the predictive equation for M_t and t can be used to determine drying rates (k) of water hyacinth petiole under varying sample moisture levels. The model developed for drying temperature (T) can accurately predict drying rates and forecast the minimum possible drying temperature at which drying would take longest. The time taken by water hyacinth petiole samples to dry was influenced by both the current moisture content (M_t) of the sample and the drying temperature (T). Whereas increase in drying temperature resulted into an increase in drying rate.

The significance of drying is seen in the role it plays in expelling residual intracellular fluid from the sample which could not have been expelled through dewatering. This was made possible by the breakage of water hyacinth petiole structure, including the cuticle, hence exposing the internal parts of the sample for direct drying. A study should also be carried out to establish the drying properties of water hyacinth petiole fibres separately from the tissues.

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NOMENCLATURE

k	Drying rate
h^{-1}	Per hour
^{o}C	Degree Celsius
^{o}F	Degree Fahrenheit
M_t	Current moisture content
t	time
%	Percentage
R^2	Coefficient of determination
n	Sample population